STUDY ON THE EEFECT OF VARIOUS CATALYSTS FOR BIOMASS GASIFICATION PROCESS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

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National Institute Of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, **"STUDY ON THE EFFECT OF VARIOUS CATALYSTS FOR BIOMASS GASIFICATION PROCESS"** submitted by **AMULYA KUMAR BEHERA** (109CH0103) in partial fulfillment of the requirements for the award of Bachelor of Technology degree in chemical Engineering at National Institute of Technology, Rourkela (Deemed University) and is an authentic study analysis work carried out by him under my supervision.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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ABSTRACT

The process of biomass gasification was carried out in a fluidized bed gasifier by using different biomass like rice husk, coconut coir and sugarcane bagasse as feed materials. The product gas or syngas produced was studied by varying parameters like temperature of operation, the use of catalyst as the bed material in the fluidized bed gasifier by maintaining other parameters like equivalence ratio and steam to biomass ratio constant. The process of gasification was carried out within a temperature range of 500-800^{0}C. The catalyst materials were ground and resized to a size range of 400-500micron. The bed material was prepared by mixing silica sand with dolomite and silica sand with red mud in different proportion by weight. The biomass was dried before feeding the gasifier to remove the moisture content up to the desire level of 4-5%. The syngas produced was analyzed by a portable gas analyzer. It was found that the concentration of hydrogen in the syngas increases with the increase in temperature and the amount of catalyst as the bed material in the gasifier. The concentration of other components of syngas, viz. CO_2, CH_4 and CO was observed to remain constant or decrease slightly with increase in temperature.

KEY WORDS: Fluidized bed gasifier, catalyst, rice husk, sugarcane bagasse, coconut coir, portable gas analyzer.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Gasification[1] is a process that converts organic or fossil based carbonaceous material into a combustible gas by reacting the material at high temperature with a controlled amount of air/oxygen often in combination with steam. Biomass has been a major energy source, before the discovery of fossil fuels like coal and petroleum. The role of fossil fuels presently diminishing in the developed countries, but it is still widely used in many rural communities of the developing countries for their various energy needs in terms of cooking and limited industrial use.

It has been estimated that biomass contributes around 10-14% to the total world's energy supply. The fossil fuels are considered to be the major source of energy. The rate at which the traditional fossil fuels are getting consumed, the natural reserves of coal, oil and natural gas will be consumed within 148years, 43years and 61 years[2] respectively. There are various disadvantages associated in terms of environmental impact with using fossil fuel as source of energy. The use of fossil fuels produces various pollutants and many greenhouse gases like CO_2 and many other toxic gases like SO_x and NO_x which causes global warming and acid rains. The main product of gasification process is the hydrogen gas which has the highest energy to weight ratio compared to any other fuel and it highly ecosystem friendly and renewable in nature.
Although the gasification of biomass produces ecofriendly hydrogen gases but the technology for biomass conversion is still in the development stage and can't be considered as proven technology for small and medium scale applications. The main technology barrier remains the efficient removal of the tars from the produced gas in the gasification system. This barrier can be eliminated by using different catalysts as the bed material in the fluidized bed gasifier where the process of gasification takes place as well the use of various catalyst enables the gasification process to occur at a temperature less than that of the standard temperature required and it also increases the hydrogen content of the syngas produced and thus subsequently reduces the chlorine and sulfur containing compounds present in the producer or syngas produced.

The objective of this work is to study the effects of various catalysts like red mud and dolomite in various proportions with sand on the producer gas produced by maintaining a constant equivalence ratio by using a fluidized bed gasifier by using biomass like rice husk, sugarcane bagasse, and coconut coir and as feed material

CHAPTER 2

LITERATURE REVIEWS

2.1THEORY OF GASIFICATION

Biomass gasification is a process that converts biomass in to a combustible mixture (mainly CO, H_2, CO_2 and CH_4.This is achieved by reacting the biomass at high temperatures, without combustion, with a controlled amount of oxygen, air and/or steam. It is preferable over pyrolysis for production of hydrogen because almost all the product of gasification are gases with a small amount of tar. The hydrogen produced from the gasification process can be used directly as a source of energy or used in hydrogenation process, saturate compounds and crack hydrocarbon etc. It is also used in manufacturing of different chemicals like ammonia, methanol etc.

$$\text{Biomass} + \text{heat} + \text{steam} + \text{air} \rightarrow H_2 + CO + \text{light or heavy hydrocarbons} + \text{char} \quad (1)$$

Gasification is a flexible, reliable and clean technology that can turn a variety of low-value products. It helps to reduce the dependency on foreign oil and natural gas and provides a clean alternative source of base load electricity, fertilizers, fuels and chemicals. It is a manufacturing process that converts any material such as coal, petroleum coke(petcoke) or biomass into synthesis gas (syngas). The syngas can be burned to produce electricity or further processed to manufacture chemicals, fertilizers, liquid fuels, substitute natural gas (SNG) or hydrogen. The main objective of gasification technology is to produce high concentration of hydrogen in the producer gas.

Process zones of gasification

There are four distinct process takes place in a gasifier[3] as the fuel makes its way to gasification. They are the following

- Drying of fuel: In this process zone the biomass is dried to reduce the moisture content of biomass to the desired range of 4-5%.
- Pyrolysis: This is the process zone in which tar and other volatiles are driven off.
- Combustion: in this process zone all the combustion reaction takes place in presence controlled amount of oxygen or air.
- Reduction zone: In this process zone all the reduction reactions takes place.

2.2. HYDROGEN PRODCUTION FROM BIOMASS

Major resources in biomass include agricultural crops and their waste byproducts, lingo cellulosic products such as wood and wood waste, waste from food processing and aquatic plants and algae, and effluents produced in the human habitat.

Biomass can be converted into useful forms of energy products using a number of different processes. There are two routes for biomass conversion into hydrogen-rich gas

(1) Thermochemical conversion and (2) Biochemical conversion

2.2.1 Thermo-chemical conversion

There are main three methods for biomass-based hydrogen production via thermo-chemical conversion: (i) pyrolysis, (ii) gasification, and (iii) SCWG

2.2.1.1 Pyrolysis

Pyrolysis is the process of heating of biomass at a temperature range of 650-800 K and at a pressure of 0.1-0.5MPa in the absence of air which converts convert biomass into solid charcoal, liquid oils and gaseous compounds. Pyrolysis can be classified into slow pyrolysis and fast pyrolysis based on the rate at which it proceeds. The products of slow pyrolysis is mainly charcoal which makes it unsuitable for hydrogen production. The products of fast pyrolysis can be found in all 3 phases. Gaseous products of pyrolysis include H_2, CO, CH_4, CO_2 and other gases depending on the organic nature of the biomass. The steam reforming of methane and other hydrocarbon produced can produce more hydrogen.

$$CH_4 + H_2O \rightarrow CO + 3H_2 \qquad (2)$$

The gas produced can be further enriched with H_2 through water gas shift reaction.

2.2.1.2 Gasification

Gasification is the process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the materials at high temperatures (>700 ^{0}C), without combustion, with a controlled amount of oxygen and or steam. The product gas is called syngas which has higher calorific value. There are various mechanism or reaction takes place in the gasifier at different temperature levels. The following reactions takes place in different reaction zone in a gasifier as the fuel makes its way to gasification, they are

2.2.1.2.1 Reactions

The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. In complete combustion carbon dioxide is obtained from carbon in fuel and water is obtained from hydrogen, usually as steam. The combustion reaction is exothermic and yields a theoretical oxidation temperature of 1450 ^{0}C.

The following reactions take place during gasification of biomass Basic combustion reactions

$$C + 0.5O_2 \rightarrow CO \tag{3}$$

$$C + O_2 \rightarrow CO_2 \tag{4}$$

Boudouard reaction

$$C + CO_2 \rightarrow 2CO \tag{5}$$

Water gas reaction [4]:

$$C + H_2O \rightarrow CO + H_2 \tag{6}$$

Methanation reaction

$$C + 2H_2 \rightarrow CH_4 \tag{7}$$

Shift conversion:

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{8}$$

Steam reforming of methane:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \tag{9}$$

2.2.1.2 Supercritical water gasification (SCWG)

Supercritical water gasification (SCWG) is one of the significant conversion process which takes benefits of the special properties of supercritical water (temperature above 374˚C and pressure above 22.1MPa) to convert biomass into hydrogen-rich gaseous products. By this process, biomass gets rapidly decomposed by hydrolysis and the cleavage products of biomass (mixture of CO, H_2 and methane) dissolve in the supercritical water and hence minimizing the tar and coke formation

The advantages of using this gasification technology over other gasification technology are

- Production of gaseous products in high pressure makes easy for transportation, usage, carbon capture and purification of the product gas is made through steam reforming or PSA (pressure swing adsorption).
- Higher energy efficiency is achieved in SCWG of biomass especially for high moisture content biomass as the drying process is not required in SCWG.
- The temperature of reaction is much lower than that in conventional gasification and pyrolysis. The temperature of conventional steam gasification is always above 1000°C, while the complete gasification of glucose can be achieved at 650°C, 35.4MPa in supercritical water gasification.

2.3 Catalyst and its role in gasification process

Tar formation is one of the major problems to deal with during gasification. Tar condenses at reduced temperature, thus blocking and fouling the process equipment such as engines and turbines. Various efforts have been directed on tar removal from fuel gas. Tar removal technology can be broadly divided into two approaches, they are

- Primary measures: The catalyst is incorporated or mixed with the various biomass material in the fluidized bed which achieves the catalytic gasification process which reduces the significant amount of tar from the product gas.
- Secondary measures: The syngas produced from the gasifier is treated downstream of the gasifier in a secondary reactor to remove the tar outside of the gasifier. Tar reduction reaction is kinematically limited; hence the reaction rate can be increased by increasing the reaction temperature.

- The use of catalyst as bed material in the fluidized bed can only enhance the rate for those reactions which are thermodynamically feasible. Various reactions occur in the secondary catalytic reactor downstream of the gasifier.

Catalyst to be used should have the following properties[5]

- The catalyst should be highly effective in removal of the tar from the syngas.
- It should have the capability of reforming methane.
- It should be resistant to deactivation due to carbon fouling and sintering.
- It should be strong enough to bear attrition.
- It should be less expensive

2.3.1Various catalysts used

2.3.1.1 Dolomite

It is one of the carbonate mineral which composed of carbonates of magnesium and calcium bearing the formula $CaMg(CO_3)_2$. Dolostone or dolomite rock which is primarily consisting of dolomite mineral with a stoichiometric ratio of 50% or greater content of magnesium replacing calcium. Dolomite is basically a white, gray to pink mineral which is tabular crystal type with curved surface, granular and massive in nature, trigonal crystal system and having the specific density of 2.84-2.86.

The advantages of using dolomite[6] as catalyst in the gasification process like it is inexpensive and abundantly available which attains high tar conversion up to 95% and often used as guard bed for expensive material in the fluidized bed.

The drawback of using dolomite as bed material in the fluidized bed gasifier is due of its fragile nature which quickly eroded from the fluidized bed.

The naturally available dolomite is first ground and sieved to a desired size range of 400-500 micron for use as the bed material in the fluidized bed of the gasifier.

2.3.1.2 Red mud

Red mud or red sludge is one of the solid waste product obtained from the from the Bayer process of refining of bauxite to produce the main product called alumina which is raw material from the production of aluminium by the process of Hall Heroult. A typical plant produces around two times as much red mud as alumina and that depends on the type of bauxite used in the refining process. Red mud is basically a mixture of solid and metallic oxide bearing impurities. The red colour of red mud is due to the presence iron oxide which accounts 60% of the total mass of the red mud. In addition to iron, some amounts of silica, unleached residual aluminium and titanium oxide. The red mud can be utilized as a catalyst which enhances the syngas production. The catalytic effect of red mud is due the presence of trace mount of leached residual aluminium, iron oxide and titanium oxide which contributes for high surface area of the catalyst and hence higher heating efficiency of the bed is achieved .it increase the concentration of hydrogen of the syngas produced and removes the tar associated with the syngas. The mechanical stability, thermal stability and chemical stability are 3 main factors for usability of bed material. The bed material should have high adsorption capacity in order to carry CO_2 out of the gasification zone to yield a high quality product.

2.4 GASIFIERS

Gasifier is a system which converts any kind of biomass to a mixture of combustible gas by providing the necessary components required for the partial combustion process of the biomass.

2.4.1 Types of gasifier

Since there is an interaction of air or oxygen and biomass in the gasifier, they are classified according to the way air or oxygen is introduced in it. There are basically three types of gasifier[7]. They are fixed bed, fluidized bed and entrained flow gasifier.

2.4.1.1 Fixed bed gasifier

Fixed bed gasifiers are subdivided into updraft, downdraft and cross draft gasifiers. Each type of gasifiers require fuel particles of small size (1-3 cm) to ensure an unblocked passage of gas through the bed. So the preferred biomass form is pellets or briquettes

2.4.1.1.1 Updraft gasifier:

These are the gasifiers having little tendency toward slag formation, small pressure drop and having good thermal efficiency.

Disadvantages

- Great sensitivity to tar and moisture and moisture contact of the fuel.
- Relatively long time required for the startup of IC engines.
- Poor reaction capability with heavy gas load.

2.4.1.1.2 Downdraft gasifier

Such gasifiers have flexible adaptation of gas production to feed samples.

Disadvantages

The design requires for this type of gasification is seem to be tall and not feasible for small sized fuel particles.

2.4.1.1.3 Cross draft gasifiers

In this type of gasifier there is the cross flow of the feed or biomass with the upcoming with the upcoming air/oxygen. It requires short design height, very fast response time to load, flexible gas production.

Disadvantages

This type of gasifier system is very sensitive to slag formation and incorporates high pressure drop**.**

2.4.1.2 Fluidized bed gasifier

Fluidized bed gasifier converts biomass waste products into a combustible gas that can be fired into a boiler, kilns or other types energy load. In a fluidized bed gasifier the bed material can either be sand or char or any catalyst in any combination. The fluidized bed[8] medium is usually air however, oxygen and or steam are also used. The fuel is fed into the system either above bed or directly into the bed, depending upon the size and density of the fuel. When a fuel particle is introduced into the environment, its drying and pyrolysis reactions proceeds rapidly driving off all gases portion of the fuel at relatively low temperature. The fluidized bed temperature must be kept below the ash melting point of the biomass, since a sticky ash might glue together with bed particles causing agglomeration and breakdown of fluidization. Hence, these are better suited for materials having high ash melting point e.g. woody bio-material (above 1000°C).

There are two types of fluidized bed reactors used for the process of gasification. They are

Bubbling fluidized bed (BFB) and circulating fluidized bed (CFB).

Advantages of fluidized bed gasifier

- Fluidized bed gasifier improves both heat and mass transfer.
- Reduces tar formation.
- It does not encounter scaling up problem
- Flexibility in terms of operation and size of feed stock.

2.4.1.3 Entrained flow gasifier

This type of gasifier converts the mixture of biomass and oxygen into a turbulent dust flame at a temperature of 2000^0 C for a very short period of time and at high pressure (about 50 bars). The feed stock is pulverized to a size range of around 1 mm and liquid is converted to pyrolysis to achieve high conversion.

2.5 PREVIOUS WORKS

Walawender[9] et al. performed a series of experiments using limestone as bed material in a fluidized bed gasifier by using a mixture of mixture of 25 weight % limestone and 75 % silica sand for steam gasification of alpha cellulose with an intention of studying the behavior of the gasifier with increase in temperature. They found that substantial reduction of tar from the syngas produced and hence reduces the agglomeration process.

Baker et al.[10] studied a number of catalysts (Ni/Al_2O_3, K_2O_3,Dolomite) for pressurized steam

gasification of bagasse and wood to produce synthesis gas for methanol and ammonia production in a laboratory scale gasifier. The catalytic gasification resulted in increase in the gas yield at the expense of tar and char. They carried out the same test using some catalyst, but observed that deactivation of Ni based catalyst taken place due to carbon deposition.

Turn et al.[11] experimentally observed that the yield of hydrogen and other gases increases with increase in temperature which can be attributed to increased steam and carbon dioxide gasification reaction rates brought about by higher reactor temperatures. The concentration of higher hydrocarbon decreases with increases as reactor temperature increased, the result of more favorable conditions for thermal cracking and steam reforming reactions. The yield of hydrogen and other gases increases with decrease in Equivalence ratio the hydrogen and gas yield increases. With increasing the steam to biomass ratio the hydrogen and gas yield increases but it is least sensitive parameter compared to others.

Franco et al. [12] studied the effect of temperature and steam to biomass (Eucalyptus globules and holm-oak) ratio on gasification using atmospheric fluidized bed. It was found that the concentration of hydrogen gas increases with increase in temperature and the concentration of carbon monoxide and methane decreases. Carbon dioxide concentration remains almost constant over the temperature range. It was experimentally found that the optimum steam to biomass ratio to be 0.6-0.7 w/w.

Gavcia et al.[13] studied the effect of pine saw dust catalyst on steam gasification using a fluidized bed gasifier at a relatively low temperature of 700^0C. Nickel -Aluminium catalyst was prepared and calcined at 750^0C for 3 hours. The influence of catalyst, weight to biomass ratio, flow rate and steam to biomass ratio on the product distribution and on the quality of the gas produced was analyzed. An increase in steam to biomass ratio increases the H_2 and CO_2 yield and is observed to have positive effect on the life of the catalyst used.

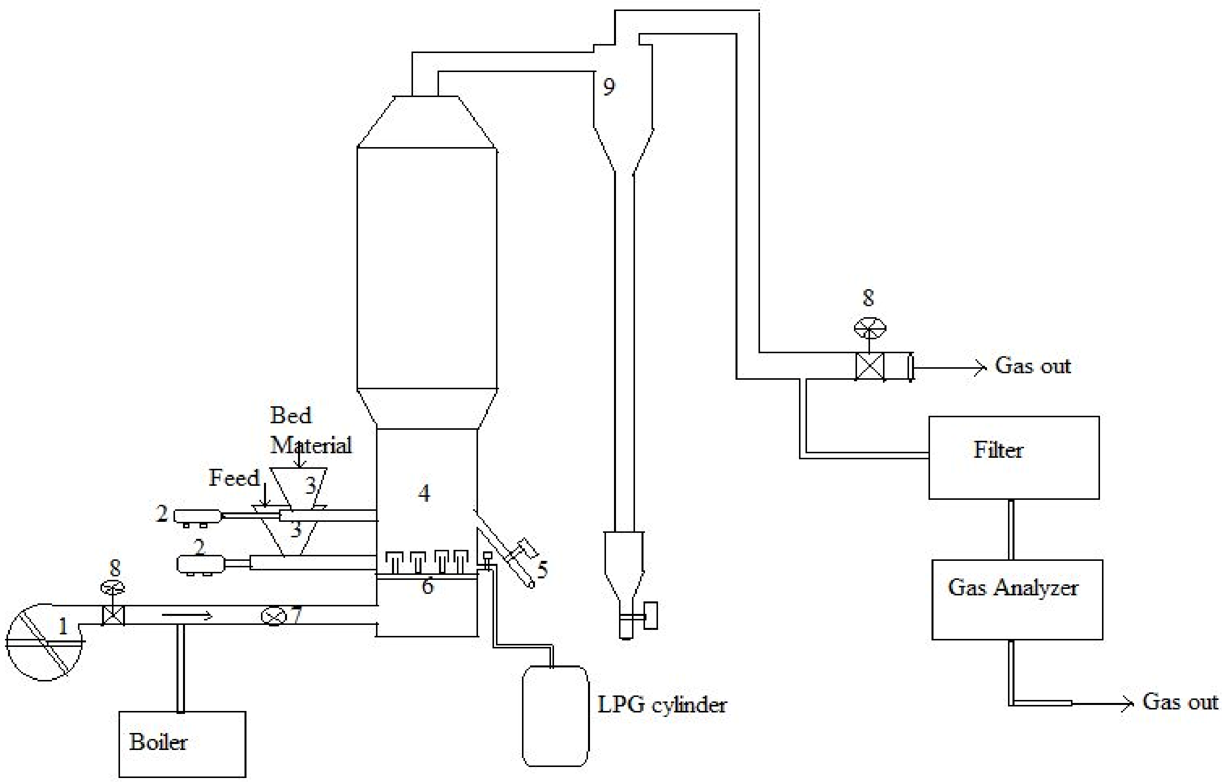
Elliot et al. [14] demonstrated that the use of catalyst in the gasification process facilitate the hydrothermal gasification, even below the critical point of water. Their initial work based without the use of catalyst. They studied the effect of the catalyst for biomass like cellulose, Douglas fir wood flour. First of all a batch test was carried out by using nickel catalyst with and without added sodium carbonates with a temperature range of 350 to 450^0C. Significant improvement in the gasification process was noticed with increase in methane content in the syngas as well as the increase in hydrogen concentration.

CHAPTER 3

EXPERIMENTATION

3.1 EXPERIMENTAL SET UP

The experimental system is a pilot plant consists of (1) atmospheric fluidized bed, (2) biomass feeding section, (3) bed material feeding section, (4) air/steam feeding section, (5) gas analysis section and (5) temperature measuring section. The gasifier was a continuous type gasifier. The experiments were carried out by using different biomass like rice husk, wooden chips, sugarcane bagasse, coconut shells as raw material and dolomite and red mud mixed with silica sand at different ratio used as bed material.



1	Air blower	6	Bubble cap
2	**Motor**	**7**	Orifice meter
3	Screw feeder	8	Valve
4	Fluidized bed gasifier	9	Cyclone separator
5	Continuous cleaning system		

Figure 1: The schematic diagram of the Experimental set up

The feeding rate of the various biomasses were controlled by the speed of the screw. Air and steam are introduced from the bottom of the gasifier. An orifice meter was used to measure the flow rates of steam and the air to the fluidized bed gasifier.

3.2 EXPERIMENTAL PROCEDURE

First of all, the biomass to be used as feed material in the fluidized bed gasifier were dried to remove the moisture content to a level of 3-4% and the catalysts like dolomite, silica sand and red mud to be used are ground and sieved to a size range of 0.4mm to 0.5 mm. Then 3 kg of the catalyst (silica sand with dolomite or silica sand with red mud with different proportion by weight) as bed material was fed to the fluidized bed reactor by the help of the screw feeder, then other components of the gasification set up like the blower, the temperature indicator and the boiler for steam generation were turned on. Then the bed was fired by using LPG at a flow rate of 10-15 LPH. After attaining the desired temperature by the bed of catalyst the flow of LPG to into the gasifier was stopped and the feed material was fed to the reactor by the help of the screw feeder and each and every valves associated with the system were checked and closed to ensure any leakage of bed material and the associated gas then the process of gasification starts.

A filter was connected to the outlet gas in which the solid particles are captured by water and the remaining particles captured by a filter of pore size of 0.01micron. the gas passes through a silica gel to remove all the moisture content of the gas and finally passes through a gas analyzer called ACE 9000X CGA portable infrared coal gas Analyzer which measures the concentration of H_2, CO, CH_4 and CO_2 in the outlet gas.

A series of experiments were carried out by using different feed material by varying the bed material composition with different ratios by weight of the catalyst. The product gas produced was analyzed with varying the temperature and the bed material composition and keeping other parameter constant like the steam to biomass ratio and equivalence ratio. The product gas was analyzed with inert free basis. Finally the plots of temperature vs concentration of syngas produced (by volume %) were plotted.

Table No. 1. Operating parameters studied and their ranges

Operating parameter	Ranges
Temperature	500-800 ^{0}C
Equivalence ratio	.25
Steam to biomass ratio	0.5
Ratio of dolomite to sand	0.5 to 1
Ratio of red mud to sand	0.5 to 1

3.3 THE GAS ANALYZER

The gas analyzer used for finding out the composition of the syngas produced in the gasification process is commercially known as Portable gas analyzer (Item code: ACE 9000X-CGA). It measures the concentration of CO, CO_2, CH_4, H_2 and O_2 in sample gases simultaneously. For this an infrared sensing technology is introduced inside the analyzer. The list count for the concentration measurement is 0.001. Some of the special features of this analyzer are automatic calorific value calculation, automatic zero calibration, built-in sampling pump.

3.4 EXPERIMENTAL ANALYSIS

3.4.1 Experiment no.1

Effect of varying temperature on syngas composition at constant steam to biomass ratio and equivalence ratio

Biomass: Rice husk, Steam to biomass ratio: 0.5

Biomass feed rate: 10kg/hour, Bed material: silica sand

Table no. 2 Syngas composition on inert free basis (volume %) with different temperature

Temperature(^{0}C)	H_2 (vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	26.42	26.77	8.02	32.21
550	31.74	25.42	7.62	37.42
600	33.26	23.42	7.52	36.81
650	35.87	24.92	8.91	34.72
700	36.32	23.43	8.63	31.63
750	36.82	22.62	7.52	29.48
800	37.62	23.42	7.68	26.73

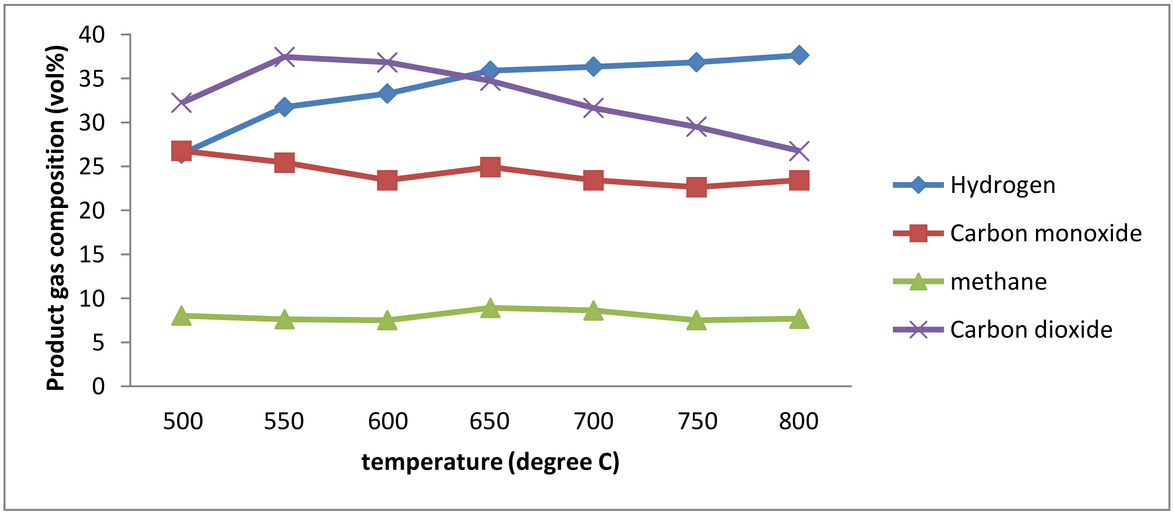


Fig No.02. Experimental product gas composition of rice husk versus Temperature

3.4.2 Experiment no. 2

Biomass: wood chips, Bed material: silica sand Equivalent ratio: 0.25,

Steam to biomass ratio: 0.5, Biomass feed rate: 10kg/hour

Table No. 3 Syngas composition on inert free basis (vol %) with different temperature

Temperature(^{0}C)	H_2 (vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	24.12	28.43	8.62	36.89
550	26.42	27.52	8.43	34.42
600	29.37	25.63	7.59	33.12
650	38.18	24.42	8.12	31.81
700	36.63	23.61	7.56	29.78
750	39.84	22.81	7.51	26.42
800	41.16	21.06	8.03	24.61

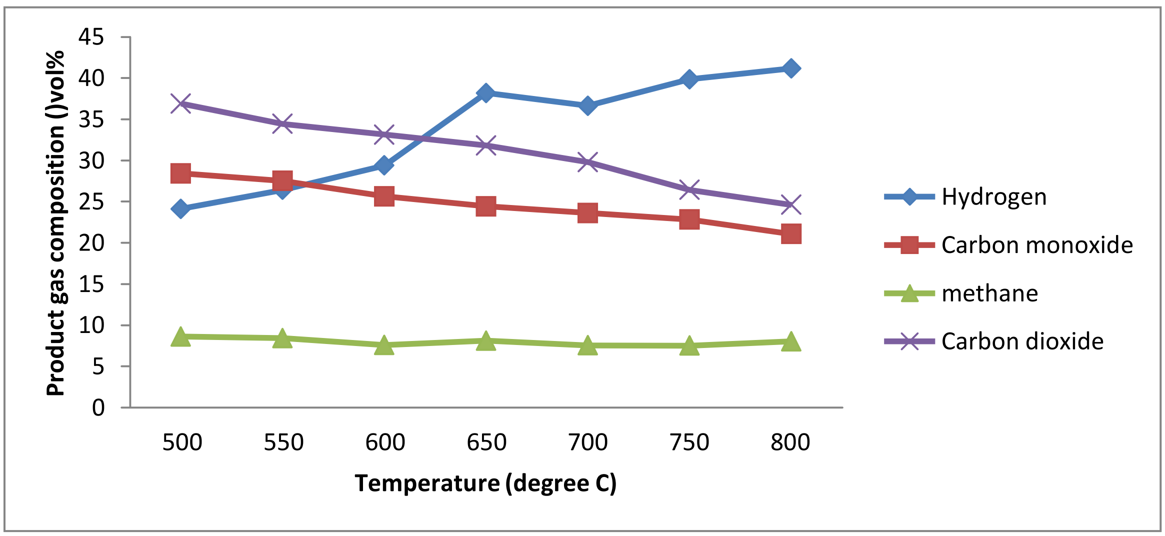


Fig No.03.Experimental product gas composition of wood chips versus Temperature.

3.4.3 Experiment no. 3

Biomass: Rice husk, equivalence ratio: 0.25

Catalyst used: Dolomite (400-500micron), dolomite to sand ratio: 1:2

Table No. 4 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	32.15	43.04	12.85	11.57
550	33.16	42.65	12.42	11.59
600	34.12	42.15	12.05	11.63
650	35.1	41.32	11.87	11.67
700	36.25	40.45	11.53	11.69
750	37.05	39.25	11.27	11.73
800	37.95	38.32	11.03	11.76

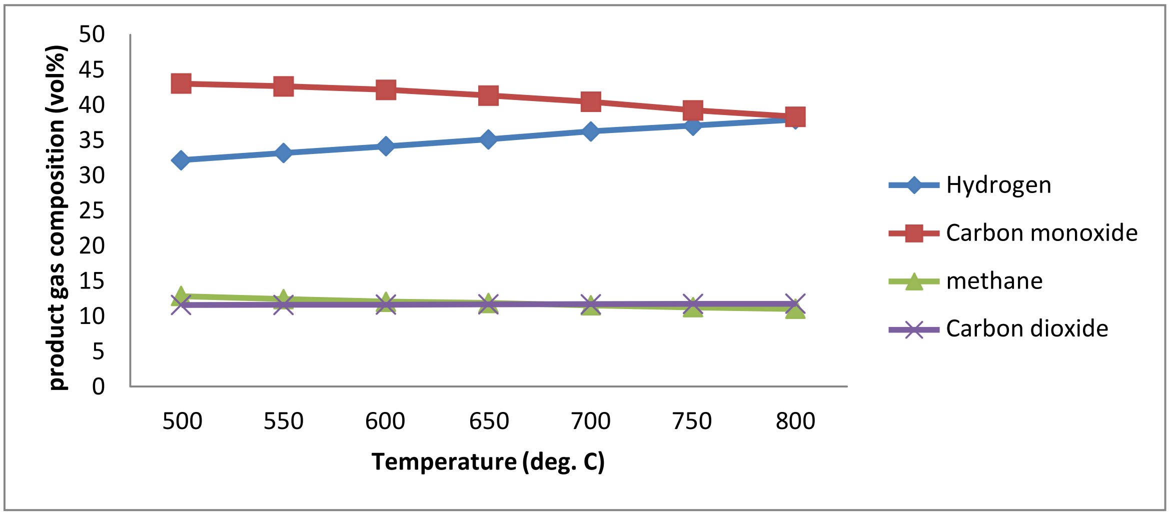


Fig No.04. Experimental product gas composition of rice husk versus Temperature with using dolomite to sand ratio 1:2

3.4.4 Experiment no. 4

Biomass: Rice husk, equivalent ratio: 0.25

Catalyst used: Dolomite (400-500micron), dolomite to sand ratio: 1:1

Table No. 05 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2 (vol%)	CO (vol%)	CH_4 (vol%)	CO_2 (vol%)
500	34.12	41.24	13.54	10.72
550	34.87	40.57	13.05	10.74
600	35.48	39.75	12.74	10.77
650	36.02	39.05	12.27	10.82
700	36.64	38.27	11.95	10.86
750	37.57	37.65	11.53	10.92
800	38.25	36.92	11.21	10.98

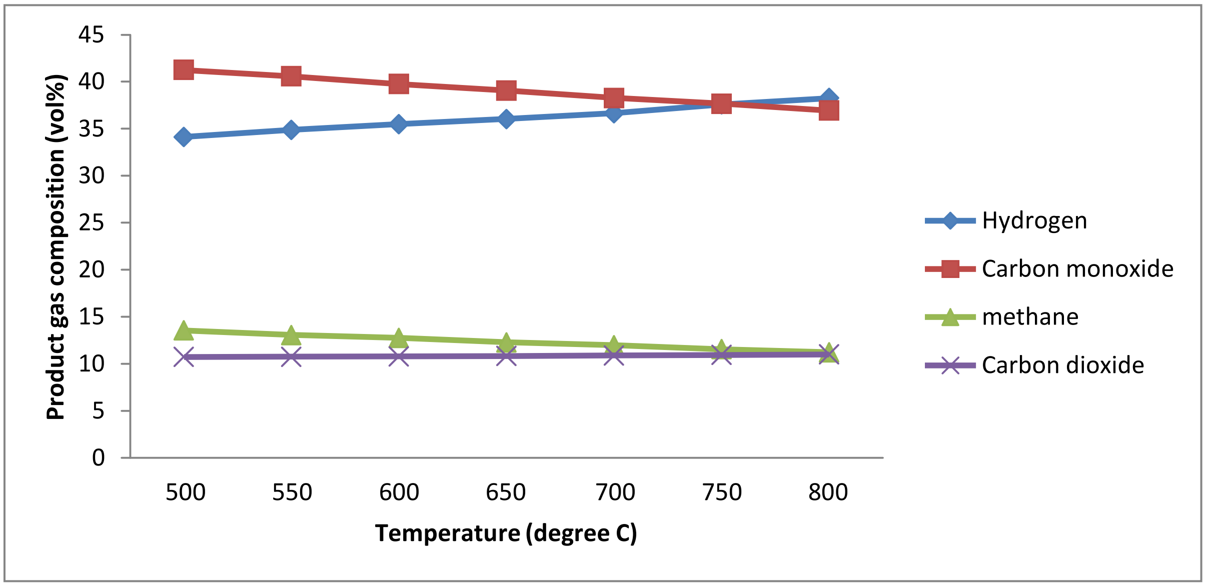


Fig No.05. Experimental product gas composition of rice husk versus Temperature with dolomite to silica sand ratio 1:1

3.4.5 Experiment no. 5

Biomass: Sugarcane bagasse, equivalence ratio: 0.25

Catalyst used: Dolomite (400 to 500micron), dolomite to sand ratio: 1:2

Table no. 06 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	31.25	45.02	13.24	10.12
550	32.47	44.31	12.86	10.24
600	33.82	43.62	12.27	10.28
650	34.54	43.03	11.82	10.34
700	35.86	42.06	11.47	10.43
750	36.72	41.24	11.03	10.52
800	37.95	40.12	10.82	10.63

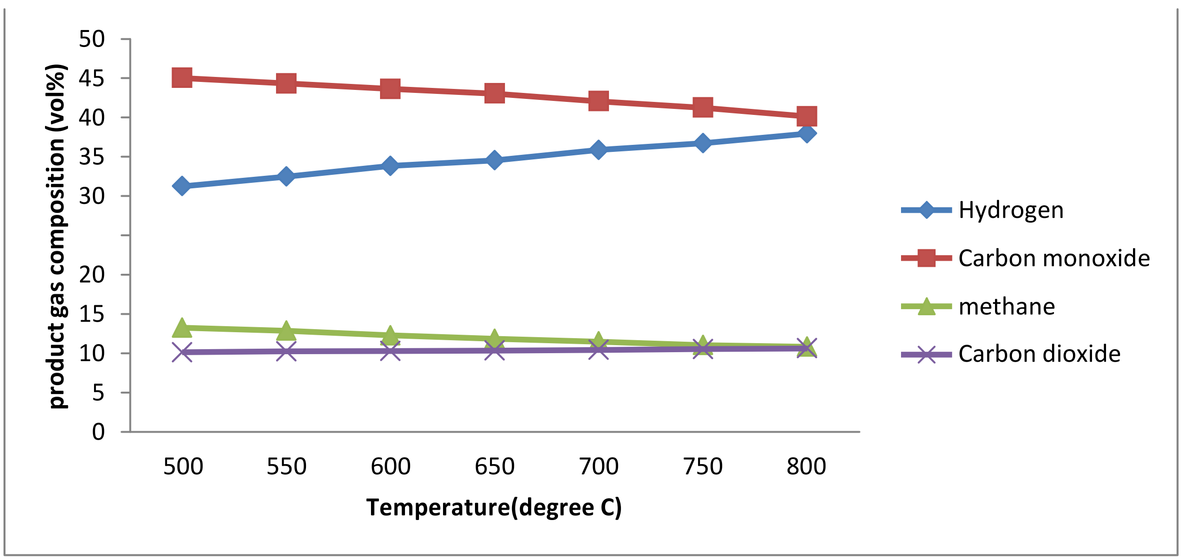


Fig No.06. Experimental product gas composition of sugarcane bagasse versus Temperature with dolomite to silica sand ratio 1:2

3.4.6 Experiment no. 6

Biomass: sugarcane bagasse equivalence ratio: 0.25

Catalyst used: Dolomite (400-500micron),dolomite to sand ratio: 1:1

Table no. 07 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	34.27	41.23	14.24	9.82
550	35.12	40.96	13.57	9.89
600	36.07	40.54	12.86	9.97
650	36.92	40.11	12.17	10.07
700	37.87	39.76	11.73	10.13
750	39.12	39.12	11.21	10.21
800	40.27	38.17	10.86	10.26

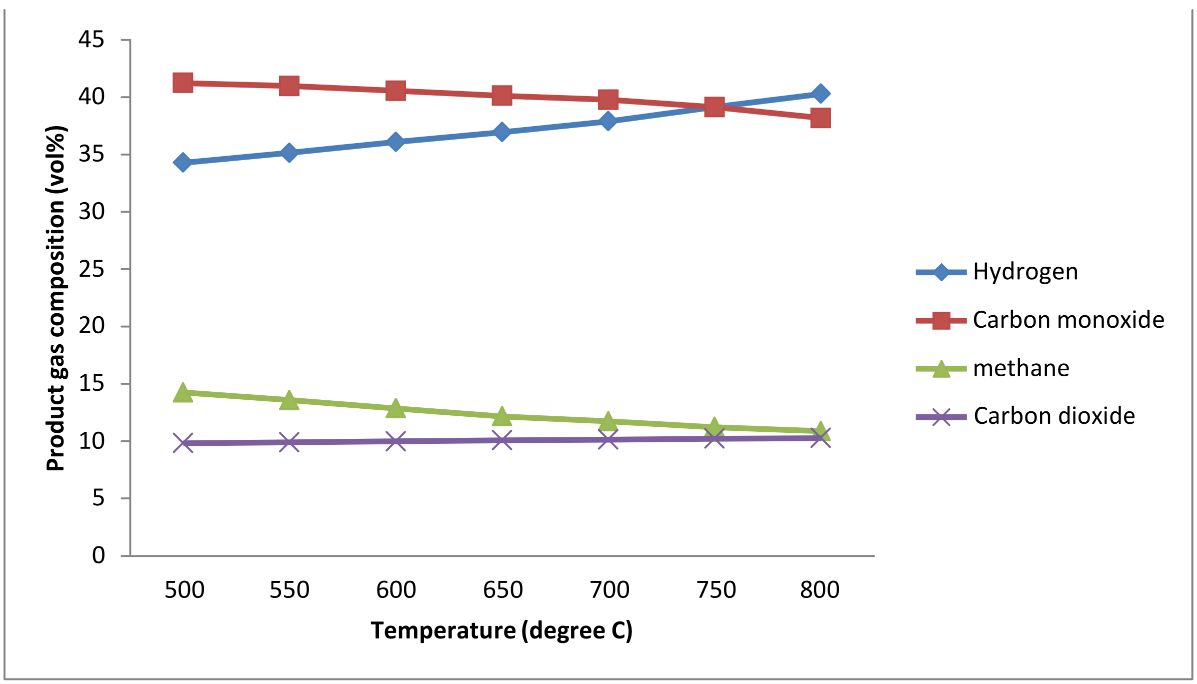


Fig No.07. Experimental product gas composition of sugarcane bagasse versus Temperature with dolomite to silica sand ratio 1:1

3.4.7 Experiment no. 7

Biomass: Sugarcane bagasse, equivalence ratio: 0.25

Catalyst used: Red mud (400-500micron), red mud to sand ratio: 1:2

Table no.08 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	37.24	36.34	18.62	7.36
550	37.96	36.98	18.12	7.58
600	38.57	35.42	17.78	7.94
650	39.15	35.02	17.22	8.32
700	39.87	34.57	17.78	8.48
750	40.47	34.25	16.24	8.69
800	40.92	34.03	15.82	8.93

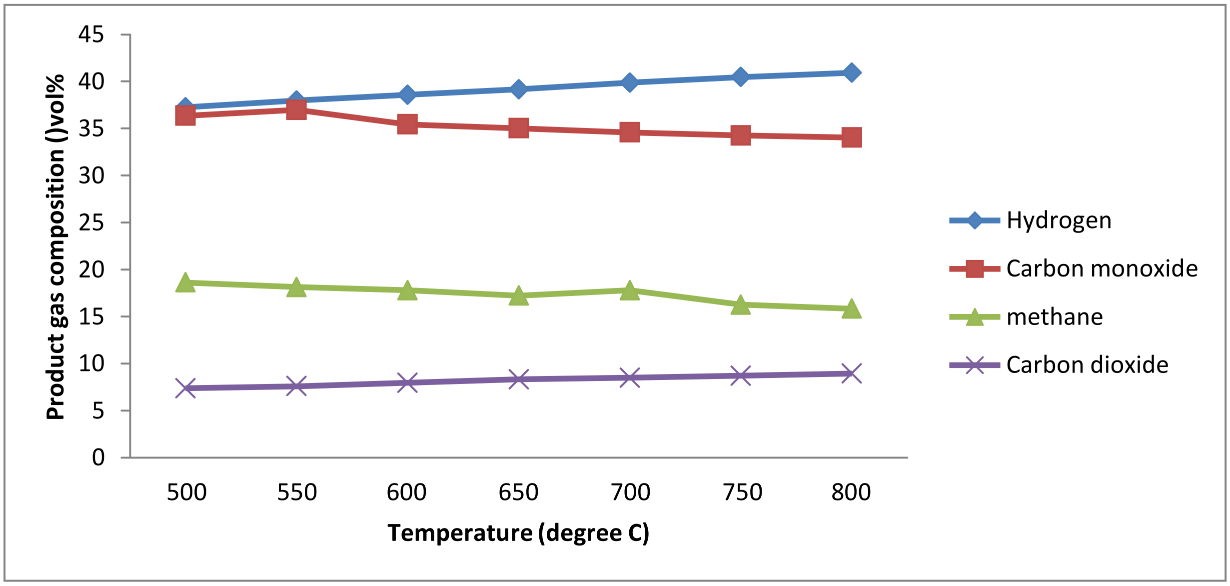


Fig No.08. Experimental product gas composition of sugarcane bagasse versus Temperature with red mud to silica sand ratio 1:2

3.4.8 Experiment no. 8

Biomass: sugarcane bagasse, equivalence ratio: 0.25

Catalyst used: Red mud (400-500micron), red mud to sand ratio: 1:1

Table no. 09 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	38.12	35.54	19.21	6.86
550	38.92	34.78	19.05	6.98
600	39.47	34.35	18.72	7.2
650	39.86	34.03	18.48	7.35
700	40.57	33.44	18.32	7.45
750	41.12	33.18	17.92	7.58
800	41.98	32.51	17.68	7.72

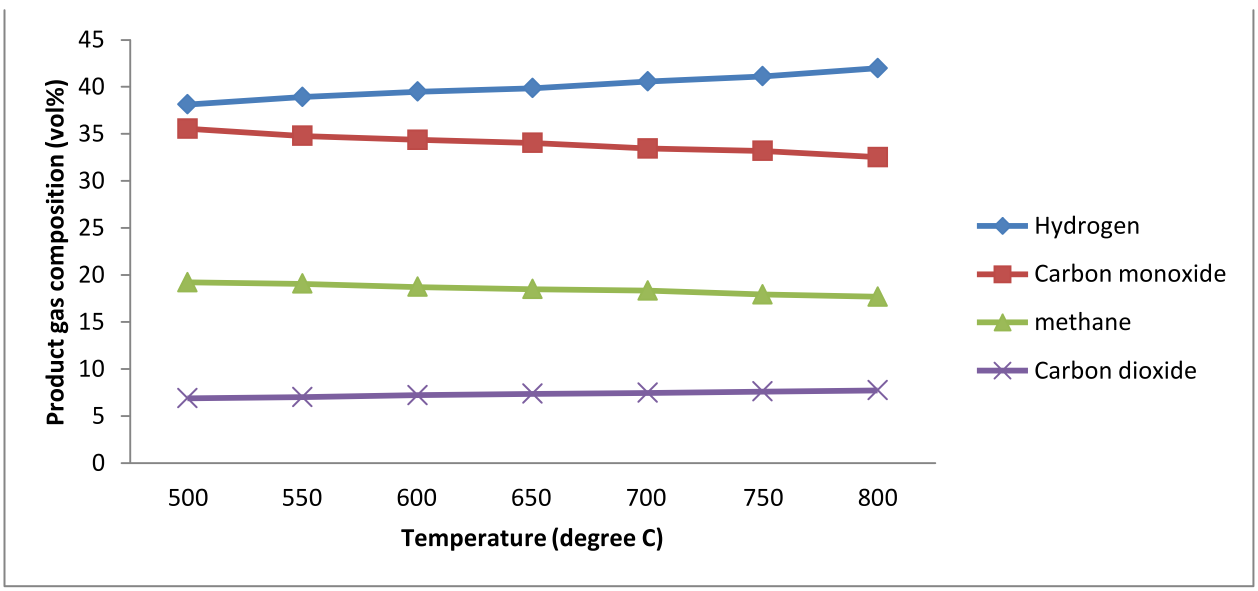


Fig No.09. Experimental product gas composition of sugarcane bagasse versus Temperature with red mud to silica sand ratio 1:1

3.3.9 Experiment no. 9

Biomass: Rice husk, equivalence ratio: 0.25

Catalyst used: Red mud (400-500micron), red mud to sand ratio: 1:2

Table no.10 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	35.54	39.06	16.24	8.86
550	36.24	38.76	15.56	8.96
600	36.92	38.54	14.82	9.12
650	37.87	38.32	13.72	9.27
700	38.42	38.17	12.57	9.35
750	39.87	37.87	11.69	9.49
800	40.25	37.43	11.02	9.58

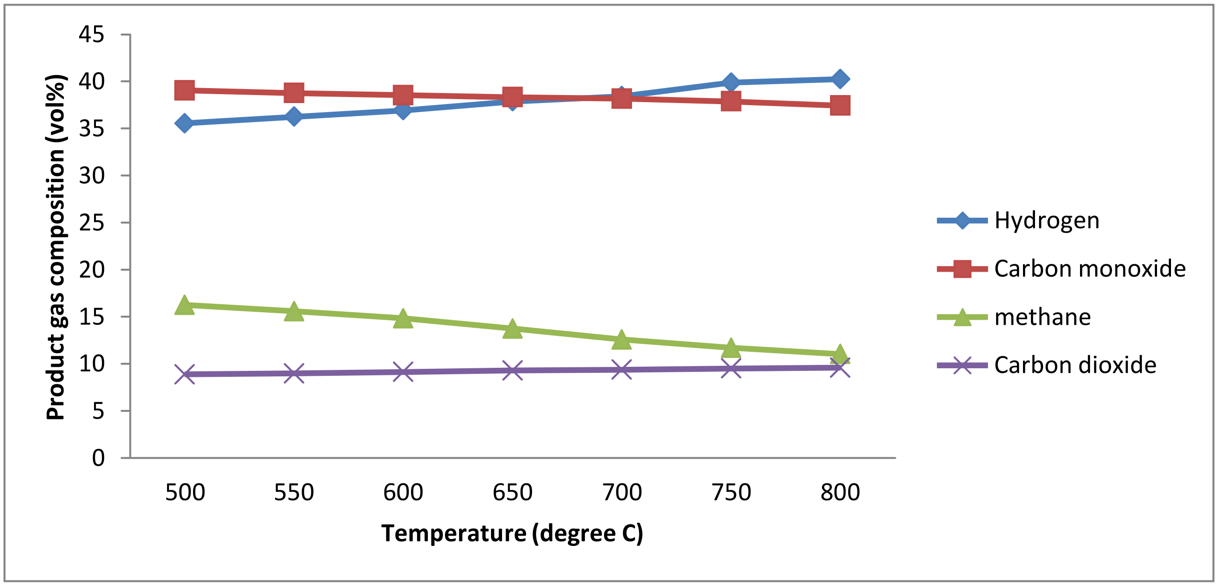


Fig No.10. Experimental product gas composition of rice husk versus Temperature with red mud to silica sand ratio 1:1

3.3.10 Experiment no. 10

Biomass: Rice husk, Equivalence ratio: .25

Catalyst used: Red mud (400-500micron), Red mud to silica sand: 1:1

Table no. 11 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	37.42	37.36	16.24	8.86
550	38.15	36.87	15.38	9.27
600	39.24	36.05	14.92	9.54
650	39.97	35.87	14.12	9.68
700	40.82	35.25	13.78	9.84
750	41.56	34.78	13.19	10.17
800	42.82	33.83	12.82	10.32

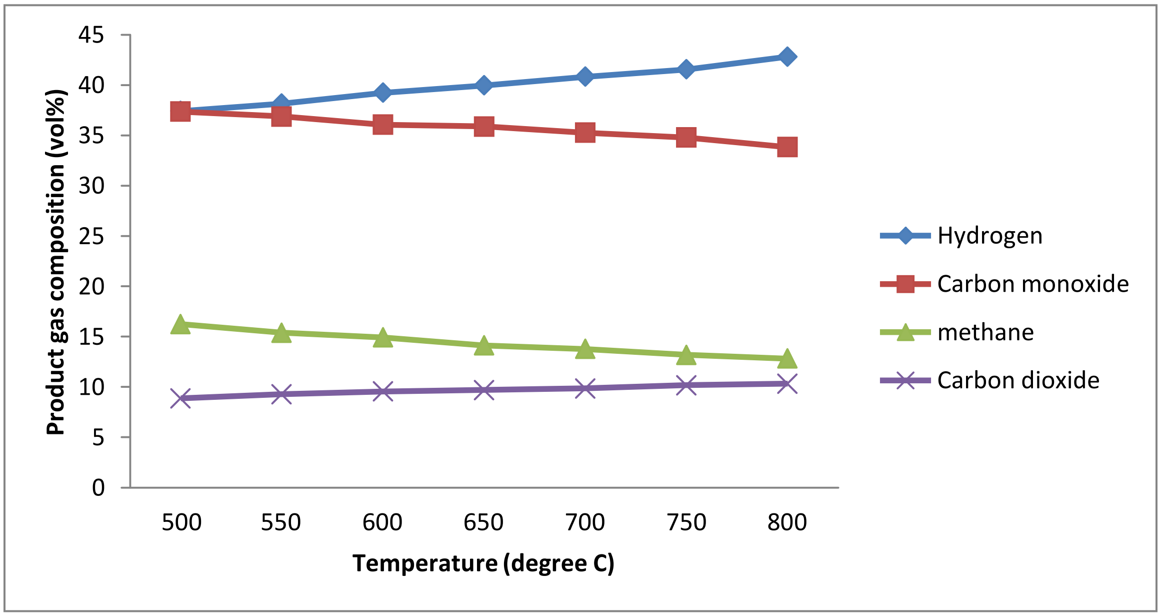


Fig No.11. Experimental product gas composition of rice husk versus Temperature with red mud to silica sand ratio 1:1

3.3.11 Experiment no. 11

Biomass: Coconut coir, Equivalence ratio: 0.25

Catalyst used: Dolomite (400-500micron), Dolomite to sand ratio: 1:2

Table no. 12 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	30.12	36.27	14.75	18.82
550	30.96	35.52	14.31	18.12
600	31.57	34.89	13.91	17.56
650	32.27	34.12	13.28	17.15
700	33.41	33.43	12.78	16.53
750	34.16	32.82	12.12	16.02
800	35.91	31.95	11.81	15.62

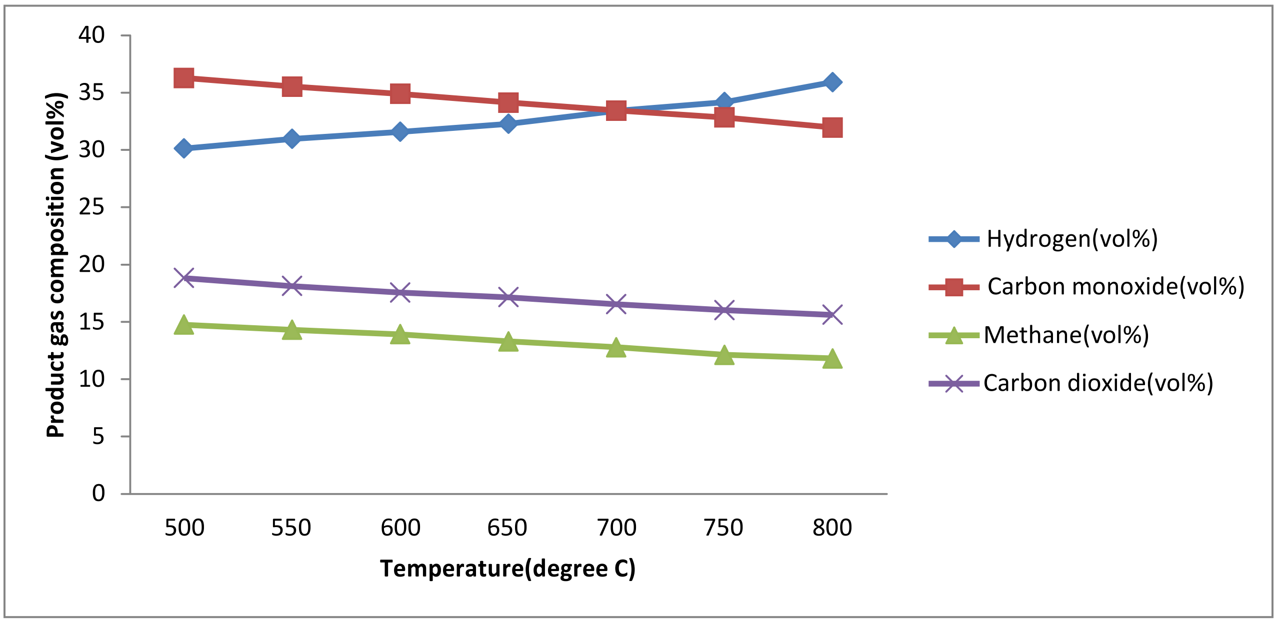


Fig No.12. Experimental product gas composition of coconut coir versus Temperature with dolomite to silica sand ratio 1:2

3.3.12 Experiment no. 12

Biomass: Coconut coir, Equivalence ratio: 0.25

Catalyst used: Dolomite (400-500micron), Dolomite to sand ratio: 1:1

Table No. 13Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	32.26	44.18	15.23	8.12
550	32.92	43.78	14.95	7.87
600	33.47	43.21	14.78	7.61
650	33.89	42.83	14.39	7.38
700	34.41	42.57	14.13	7.13
750	34.78	42.18	14.01	6.89
800	35.34	41.96	13.81	6.64

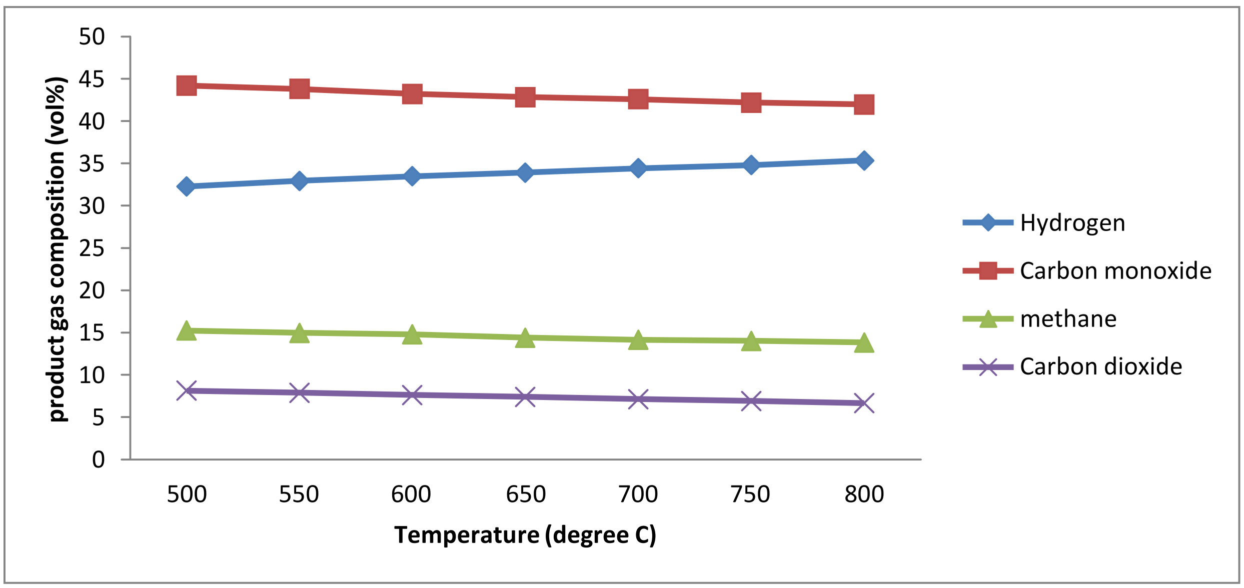


Fig No.13. Experimental product gas composition of wood coconut coir versus Temperature with dolomite to silica sand ratio 1:1

3.3.13 Experiment no. 13

Biomass: Coconut coir, Equivalence ratio: 0.25

Catalyst used: Red mud (400-500micron), Red mud to sand ratio: 1:2

Table no. 14 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	34.78	42.27	12.62	9.92
550	35.52	41.72	12.28	9.87
600	36.27	41.18	12.03	9.78
650	36.98	40.78	11.81	9.62
700	37.44	40.34	11.53	9.41
750	37.89	39.57	11.27	9.34
800	38.38	38.76	10.93	9.22

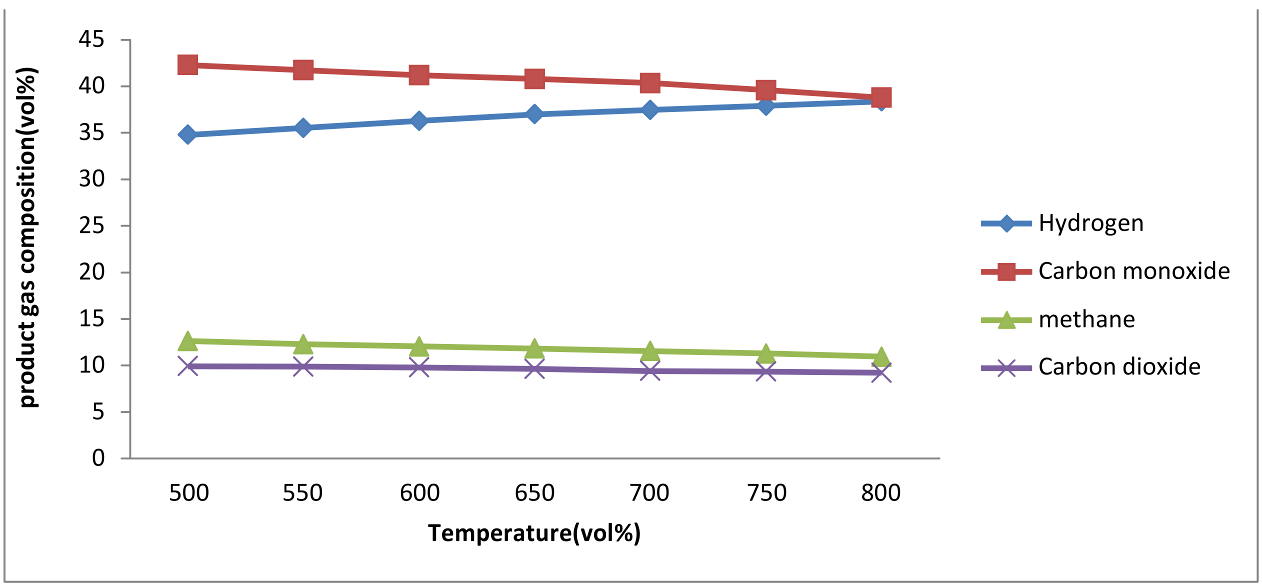


Fig No.14. Experimental product gas composition of red mud versus Temperature with red mud to silica sand ratio 1:2

3.3.14 Experiment no. 14

Biomass: Coconut coir, Equivalence ratio: 0.25

Catalyst used: Red mud (400-500micron), Red mud to sand ratio: 1:1

Table No. 15 Syngas composition on inert free basis (volume %) with different temperature

Temperature (^{0}C)	H_2(vol%)	CO (vol%)	CH_4 (vol%)	CO_2(vol%)
500	37.42	39.71	14.12	8.24
550	37.97	39.31	13.78	8.07
600	38.52	39.05	13.53	7.91
650	38.89	38.68	13.34	7.87
700	39.47	38.24	13.12	7.81
750	39.72	37.85	12.87	7.73
800	40.28	37.52	12.67	7.62

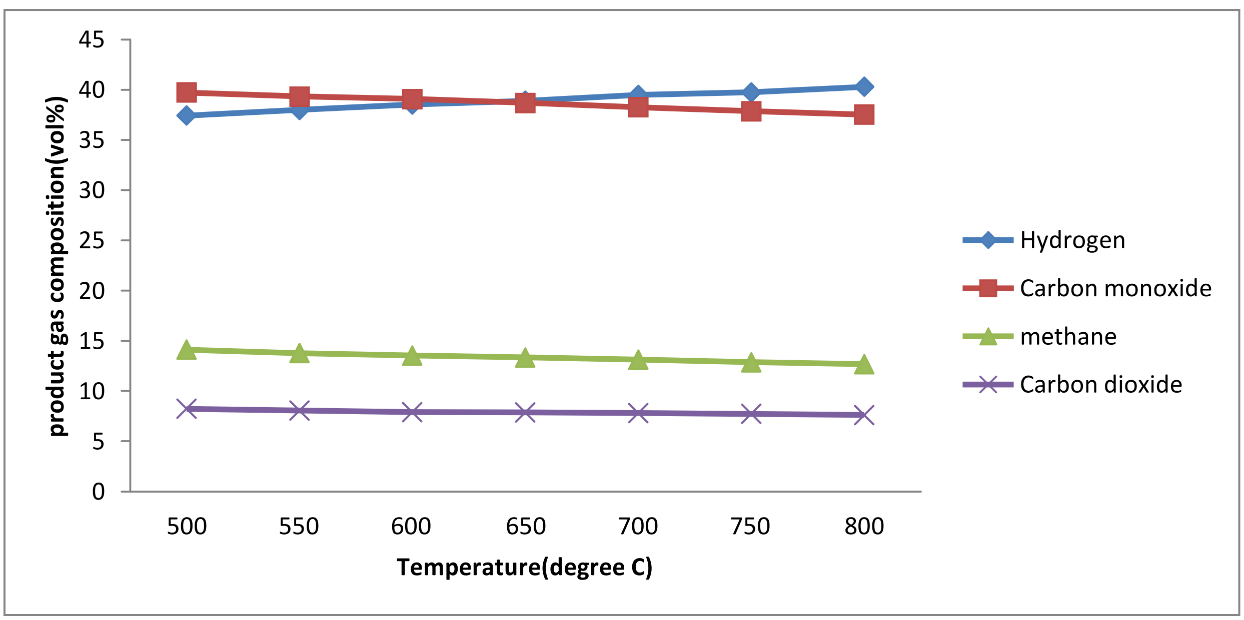


Fig No.15. Experimental product gas composition of coconut coir versus Temperature with red mud to silica sand ratio 1:1

CHAPTER 4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Table no.16 Catalytic effect on H_2 content of syngas for rice husk

Temperature (°C)	Without catalyst	With dolomite as catalyst	With red mud as catalyst	% Increase in H_2 content using dolomite	%Increase in H_2 content using red mud
500	26.46	34.12	37.24	28.94936	40.74074
550	27.84	34.87	38.15	25.25144	37.03305
600	28.24	35.48	39.24	25.63739	38.95184
650	28.38	36.02	39.97	26.92037	40.83862
700	29.64	36.64	40.82	23.61673	37.7193
750	30.38	37.57	41.56	23.66689	36.80053
800	31.69	38.25	42.82	20.70054	35.12149

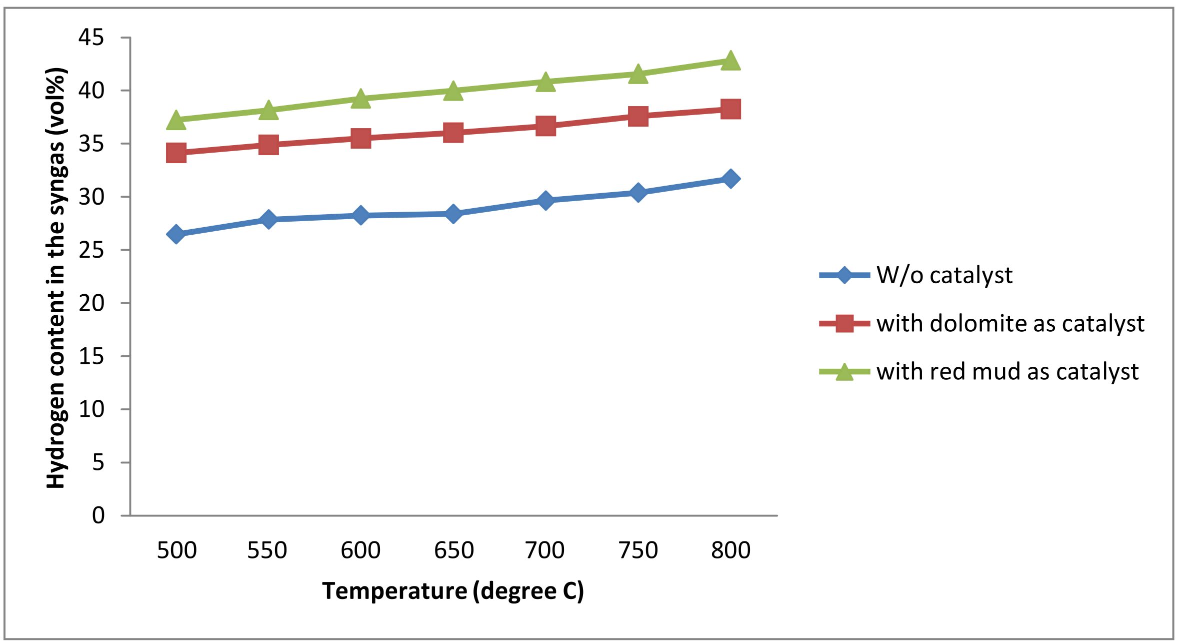


Fig. no 16. Effect of catalyst on H_2 content of syngas with temperature for rice husk

Table no. 17 Effect of catalyst on H_2 content of syngas using sugarcane bagasse

Temp (^oC)	Without catalyst	with dolomite as catalyst	with red mud as catalyst	% increase in H_2 content using dolomite	% increase in H_2 content using red mud
500	28.02	34.27	38.12	22.3055	36.04568
550	28.17	35.12	38.92	24.67164	38.16116
600	29.34	36.07	39.47	22.93797	34.52624
650	29.29	36.92	39.86	26.04985	36.0874
700	30.16	37.87	40.57	25.56366	34.51592
750	31.24	39.12	41.12	25.22407	31.62612
800	32.42	40.27	41.98	24.21345	29.48797

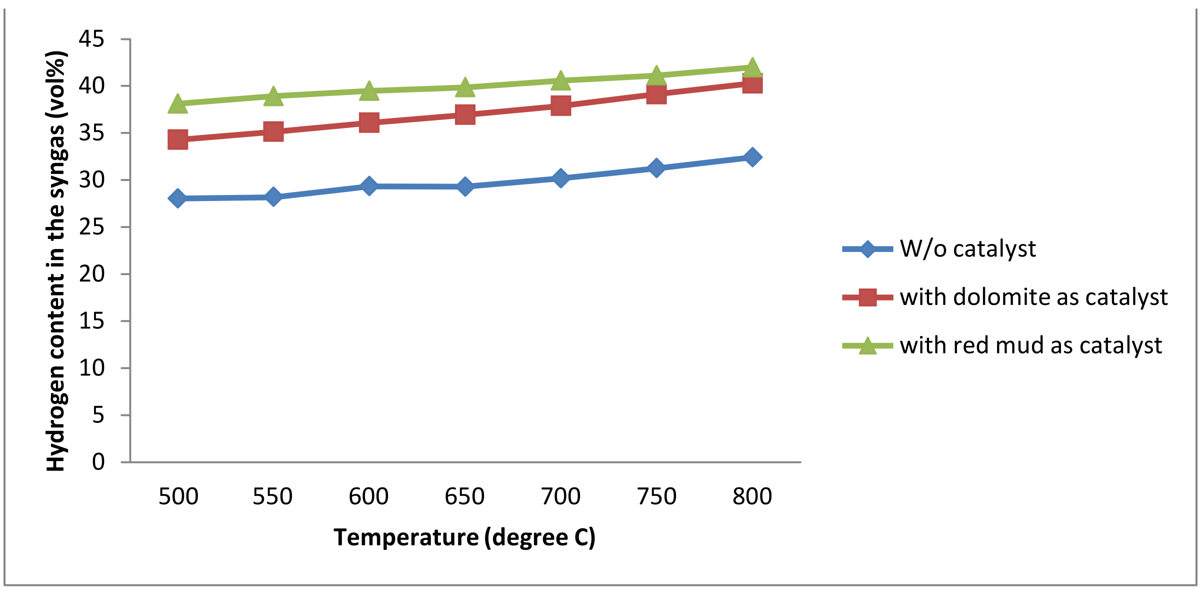


Fig. no. 17 Catalytic effect on H_2 content of syngas with temperature for sugarcane bagasse

Table no18. Catalytic effect on H_2 content of syngas using coconut coir.

Temp (^oC)	Without catalyst	with dolomite as catalyst	with red mud as catalyst	% increase in H_2 content using dolomite	% increase in H_2 content using red mud
500	26.46	32.26	37.42	21.91988	41.42101
550	27.84	32.92	37.97	18.24713	36.38649
600	28.24	33.47	38.52	18.51983	36.40227
650	28.38	33.89	38.89	19.41508	37.03312
700	29.64	34.41	39.47	16.09312	33.16464
750	30.38	34.78	39.72	14.48321	30.74391
800	31.69	35.34	40.28	11.51783	27.10634

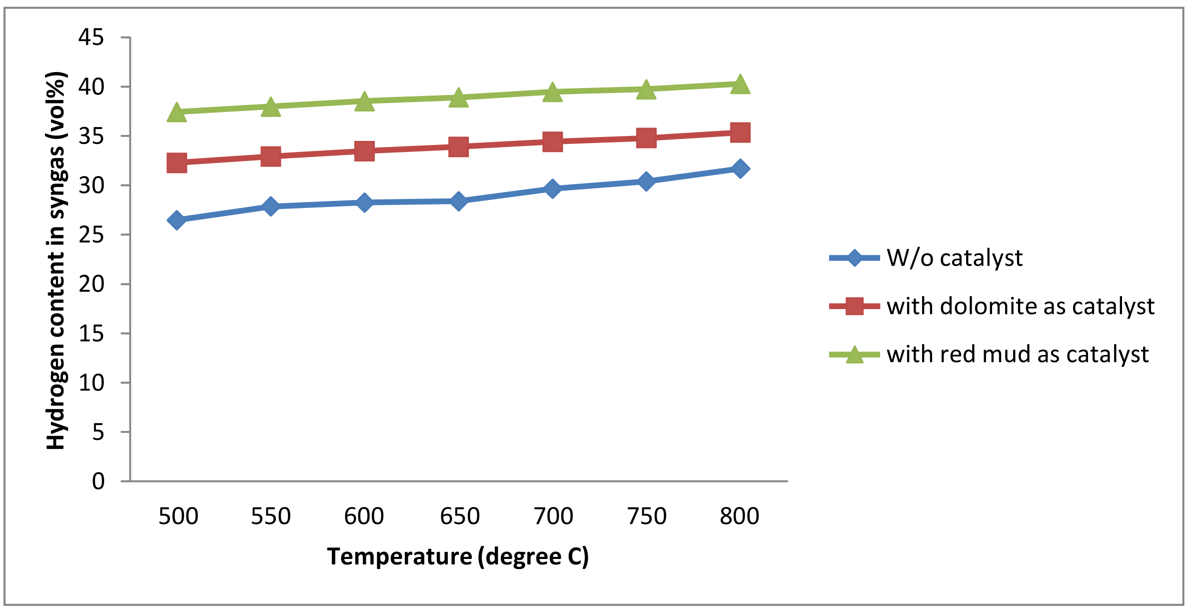


Fig no. 18 Catalytic effect on H_2 content of syngas with temperature using coconut coir

A series of experiments were carried out by using biomass like rice husk, sugarcane bagasse and coconut coir as feed material with mixture of silica sand with dolomite and silica sand with red mud in different proportion by weight. The effect of various parameters like temperature and the proportion of the catalyst used on the syngas production were studied by keeping other parameters like steam to biomass ratio, equivalence ratio constant by the help of a portable gas analyzer.

It was found experimentally that the concentration of hydrogen increases with increase in temperature and the amount of other gases remains constant or slightly decreases with increase in temperature. The hydrogen content of the syngas is much higher with use of catalyst than without catalyst. The percentage increase in hydrogen yield decreases with increasing in temperature because at higher temperature the surface of the catalyst is covered with carbon particle which ultimately reduces the catalytic effect.

The concentration of methane gas was found to be decreasing with increase in temperature as at higher temperature cracking and steam reforming of methane favors. The concentration of dioxide decreases with increase in temperature as at higher temperature favors endothermic formation of CO from CO_2 via boudouard reaction.

CHAPTER 5

CONCLUSION

CONCLUSION

The gasification process was carried out successfully and the variation of syngas composition with temperature and the presence of various catalysts were studied by keeping other parameters like equivalence ratio and steam to biomass ratio constant. It has also found that red mud has higher catalytic effect than dolomite in terms of hydrogen production, as it contains many metal contents like iron, some amounts of silica, unleached residual aluminium and titanium oxide. The red mud used as the catalyst is a powdered substance which enables good mixing with the bed and enhances fluidization .As hydrogen contributes the maximum for the calorific value of the syngas, so syngas of high calorific value can be obtained by using various catalysts as bed material.

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